

N91-20657

BERTHING SIMULATOR FOR SPACE STATION AND ORBITER

Dr. Sam Veerasamy, P. E.
Principal Engineer
Simulation Development Department
Lockheed Engineering and Sciences Company
2400 Nasa Road 1, C83, Houston, TX 77058

ABSTRACT

The development of a real-time man-in-the-loop berthing simulator is in progress at NASA Lyndon B. Johnson Space Center (JSC) to conduct a parametric study and to measure forces during contact conditions of the actual docking mechanisms for the Space Station Freedom and the orbiter. In berthing, the docking ports of the space station and the orbiter are brought together using the orbiter robotic arm to control the relative motion of the vehicles. The berthing simulator consists of a dynamic docking test system (DDTS), computer system, simulator software, and workstations. In the DDTS, the space station and the orbiter docking mechanisms are mounted on a six-degree-of-freedom (6 DOF) table and a fixed platform above the table. Six load cells are used on the fixed platform to measure forces during contact conditions of the docking mechanisms. Two Encore Concept 32/9780 computers are used to simulate the orbiter robotic arm and to operate the berthing simulator. A systematic procedure for a real-time dynamic initialization is being developed to synchronize the space station docking port trajectory with the 6 DOF table movement. The berthing test can be conducted manually or automatically and can be extended for any two orbiting vehicles using a simulated robotic arm. The real-time operation of the berthing simulator is briefly described in this paper.

INTRODUCTION

Berthing is the joining of docking ports of any two orbiting vehicles using a robotic arm to control the relative motion of the vehicles while docking uses on-board propulsion system to perform the same task. During and after construction of the space station, it will be necessary to transport large quantities of materials, consumables, crew, life supporting items, etc., to and from the space station. Berthing is preferred over docking, because relative velocities and impact loads are smaller than those for docking. Further, there will be no plume impingement on the space station during berthing. Since the space station is to be manned, on-board manual control that uses direct control and/or remote

visual cues appears to be the simplest method of control for the berthing maneuver.

The real-world berthing operation is shown in figure 1. The space station is captured by the end effector of the orbiter robotic arm or the 6 DOF remote manipulator system (RMS). The orbiter and the space station docking ports are denoted by DP1 and DP2 respectively. The berthing operation starts after the RMS captures the space station. The DP2 is the point of resolution (POR) for the orbiter RMS. The RMS is commanded to control the relative distance and attitude of the docking ports. The docking ports slowly come to initial contact for soft latch, and finally hard latch. During the initial construction phase of the space station, the orbiter RMS will be used for berthing operation. After construction is completed, a 7 DOF space station RMS will be used for berthing.

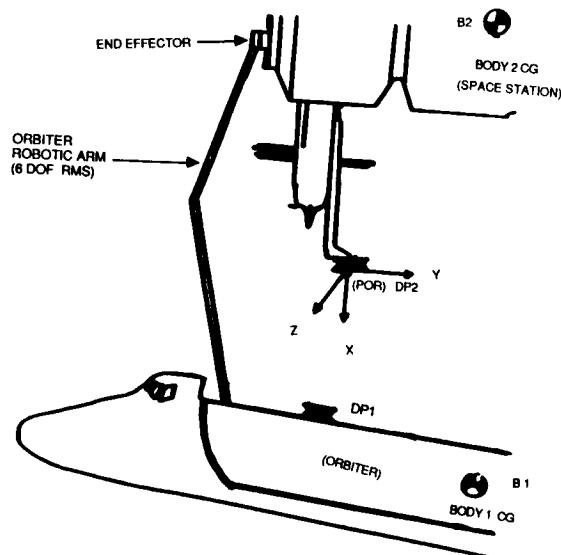


Figure 1. REAL-WORLD BERTHING OPERATION

A real-time berthing simulator is being developed at NASA/JSC to conduct a detailed parametric study of the actual docking mechanisms for the space station and the orbiter. The berthing study will examine position and attitude misalignments, linear and angular velocities, contact forces and latching of the

docking mechanisms. The simulator consists of a DDTS, two Encore Concept 32/9780 computers, simulator software, and workstations. A closed circuit television (CCTV) monitoring system provides views of the docking mechanisms and alignment aids. The simulator software models consist of the RMS control system, the RMS dynamics, the RMS geometry, the docking port relative geometry, the actuator command, the load cell forces and moments, and the physical characteristics of the orbiter, the 6 DOF table and a particular space station configuration. The berthing simulation models are designed to grow as new requirements develop. The hardware and software components and the real-time berthing operations are briefly described in this paper.

DDTS

Figure 2 shows the DDTS used for berthing operation and a perspective view of the DDTS is shown in figure 3. The 6 DOF table is driven by six coupled hydraulic actuators(1). The actual space station and orbiter docking mechanisms to be tested are mounted on the 6 DOF table and the fixed platform above the table. The position and velocity of the table are controlled by commanding the six hydraulic actuators. The contact forces are measured by three pairs of calibrated load cells, mounted between the body 1 docking ring and body 1 mounting ring as shown in figure 4. The load cells are mounted in equidistance around the ring to obtain a three dimensional force vector by resolving the individual load cell forces. The load cell output voltage is assumed to be proportional to the applied force and is zeroed to compensate the orbiter docking mechanism hanging from the body 1 fixture. The output of the load cells are provided to the load cell forces and moments model through analog to digital converters. The real-time software model is executed at 50 Hz.

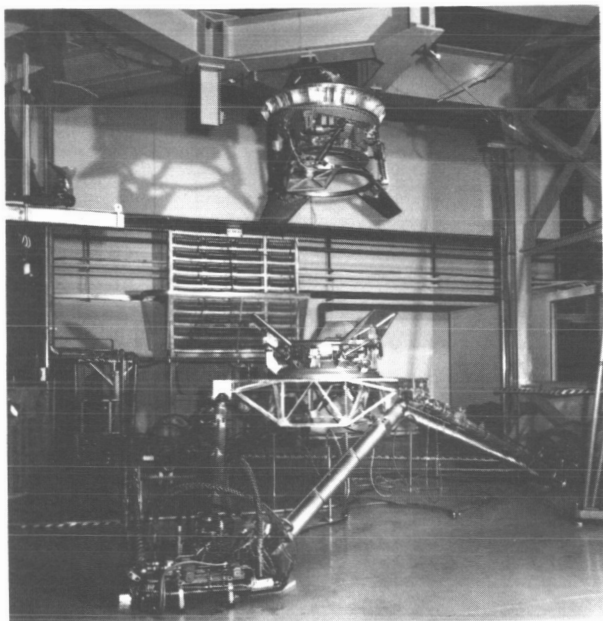


Figure 2. DYNAMIC DOCKING TEST SYSTEM

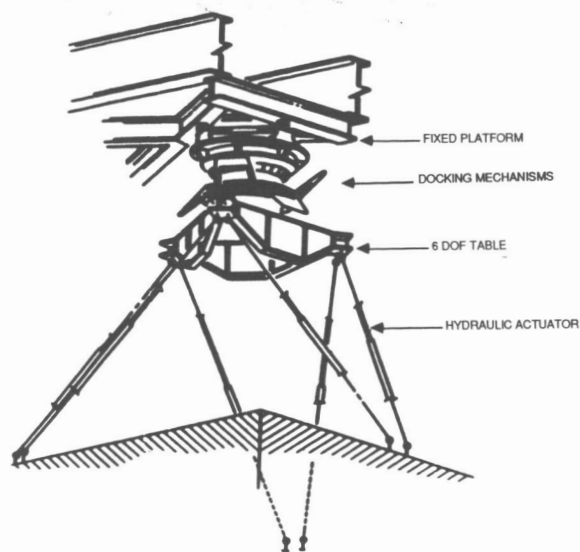


Figure 3. PERSPECTIVE VIEW OF THE DDTS

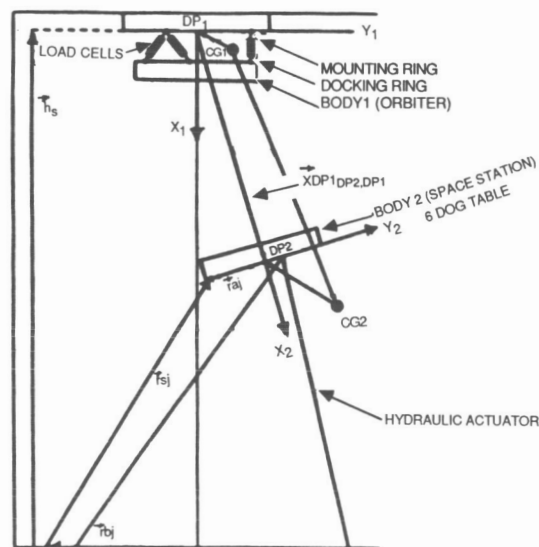


Figure 4. DDTS GEOMETRY

The DDTS can be safely operated up to 3,000 lb impact force with 2 lb resolution. The height of the 6 DOF table can be controlled vertically from 4.24 ft to 14.63 ft with a resolution of 0.006 in by commanding the hydraulic actuators. The attitude (roll, yaw and pitch) of the 6 DOF table can be controlled within $\pm 20^\circ$. When the docking mechanisms are not installed, the table can travel a vertical distance of 10 ft. The sidewise movement of the table can be controlled within ± 3 ft.

RMS SOFTWARE

The RMS is modeled as a six joint flexible robotic arm. The RMS dynamics and control system models provide a reasonable accuracy at docking port contact conditions and maintain stability for the simulation. The software is already in use in a real-time simulation(2). The RMS model is tailored to meet the requirements for the berthing simulation (3).

In a real-time operation, RMS dynamics and control system models run at 50 Hz and 25 Hz respectively. Malfunctions and capture/release transitions are not simulated. The effect of non-linear torque is assumed to be negligible. As gravity forces and gravity gradient forces are small compared to contact forces and moments, the gravity gradient effects are neglected. The docking port relative geometry is computed using the orbiter RMS POR position and attitude.

WORKSTATIONS

The simulator workstation consists of an 80386-based 33 MHz computer with a math co-processor, and printers to monitor and dump real-time data and post process data. This workstation supports dry runs, man-in-the-loop runs, berthing programmed test input runs, simulator readiness tests and health status tests. During dry runs, the real-time software system is operational, but the hardware system (hydraulic actuators, load cells etc.) is not powered.

The RMS workstation consists of two closed circuit television (CCTV) monitors, two hand controllers and a graphics system. The graphics system displays the difference between the simulated and the actual RMS commands as well as other status information from the simulation. This workstation provides the capability for a pilot or a RMS operator to perform a simulated berthing maneuver and monitor its progress.

DOCKING PORT RELATIVE GEOMETRY MODEL

The docking port relative geometry model receives the orbiter RMS and the space station data from the RMS geometry model and the physical characteristics of the orbiter, the space station, and the 6 DOF table. This model computes the relative position and attitude of the two docking ports for berthing operation. The real-time model is executed at 50 Hz. The output of the docking port relative geometry is sent to the actuator command model.

Figure 5 shows the docking port relative geometry. The RMS dynamics model provides POR distance ($\vec{X}_{BA DP2,BA}$) in orbiter body axis coordinates. The orbiter docking port distance ($\vec{X}_{SR1 DP1,SR1}$) is calculated in orbiter structural coordinates based on the orbiter physical characteristics. The relative distance between the docking ports in DP1 coordinates ($\vec{X}_{DP1 DP2,DP1}$) is calculated as

$$\vec{X}_{DP1 DP2,DP1} = [DP1, B1] [B1, BA] \{ \vec{X}_{BA DP2,BA} - [BA, SR1] \vec{X}_{SR1 DP1,SR1} \}$$

where $[DP1, B1]$ is the transformation matrix from B1 (body1 CG) to DP1 coordinates,
 $[B1, BA]$ is the transformation matrix from BA to B1 coordinates,
 $\vec{X}_{BA DP2,BA}$ is the POR distance in

$[BA, SR1]$

$\vec{X}_{SR1 DP1,SR1}$

orbiter body axis coordinates provided by the RMS dynamics model, is the transformation matrix from SR1 to BA coordinates,
 is the orbiter docking port distance in SR1 coordinates.

The RMS dynamics model computes POR attitude in RMS arm reference coordinates, A. Therefore, the relative attitude between the docking ports, $[DP1, DP2]$, is calculated as

$$[DP1, DP2] = [DP1, B1] [B1, A] [A, DP2]$$

where $[B1, A]$ is the transformation matrix from A to B1 coordinates,
 $[A, DP2]$ is the transformation matrix from DP2 to A coordinates.

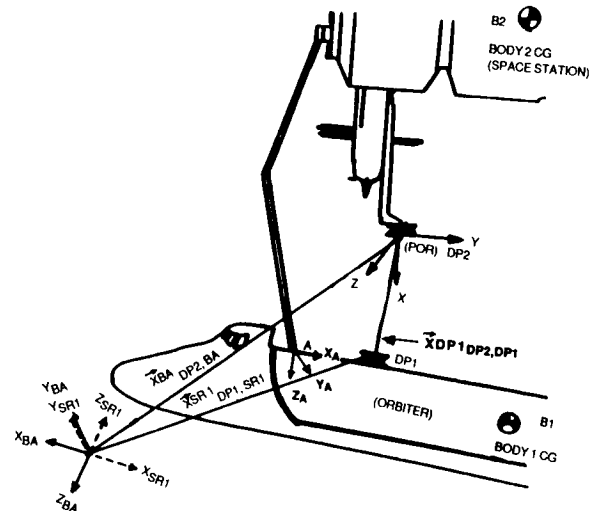


Figure 5. DOCKING PORT RELATIVE GEOMETRY

ACTUATOR COMMAND MODEL

The actuator model calculates command signals for the six hydraulic actuators. Each actuator length (\vec{r}_{sj}) is calculated as a function of the DDTS geometry, shown in figure 4, and the relative docking port geometry model.

$$\text{i.e., } \vec{r}_{sj} = -\vec{r}_{bj} + \vec{h}_s + \vec{X}_{DP1 DP2,DP1} + [DP1, DP2] \vec{r}_{aj}$$

where j represents actuator number ($j = 1, 2, \dots, 6$),
 \vec{r}_{bj} is the distance between the intersection of X1 with the base and the actuator floor pivot point in body 1 coordinates system,
 \vec{h}_s is the height between the hydraulic actuator floor pivot point and DP1 in the body 1 coordinates system,

\vec{r}_a is the distance between DP2 and the actuator table pivot point in the body 2 coordinates system.

The actuator stroke or the change in actuator length (l_{sj}) from its initial (l_{oj}) position is calculated as

$$l_{sj} = (r_{sjx}^2 + r_{sjy}^2 + r_{sjz}^2)^{1/2} - l_{oj}$$

where r_{sjx} , r_{sjy} , r_{sjz} are x,y,z components of \vec{r}_{sj} .

The position and velocity of the 6 DOF table are controlled by commanding the actuator stroke. The real-time actuator model is executed at 50 Hz.

DYNAMIC INITIALIZATION

There are two major existing hardware and software limitations for the berthing simulation. First, the maximum table travel distance in the DDTS may not be sufficient for the simulated POR travel to achieve the desired impact velocity. Second, the simulated POR in the RMS model must start with zero velocity (i.e., the RMS arm travel may require about 50 ft to attain the desired impact velocity, but the 6 DOF table will not have the capability of achieving 50 ft travel due to physical limitations of the DDTS hardware set-up). A testing capability is being developed to overcome the limitations by using dynamic initialization of the 6 DOF table and the simulated POR.

Initially, the 6 DOF table and the simulated POR will be tried to move together from the table initial condition (IC) to the final contact condition. The RMS POR initial condition is synchronized in such a way that the POR starts from the table initial condition as shown in figure 6(a). This method is called the dynamic initialization with no offset condition. The initial condition $(x, y, z, \dot{x}, \dot{y}, \dot{z}, \theta, \phi, \psi, \dot{\theta}, \dot{\phi}, \dot{\psi})$ DP2 and the final condition $(x, y, z, \dot{x}, \dot{y}, \dot{z}, \theta, \phi, \psi, \dot{\theta}, \dot{\phi}, \dot{\psi})$ DP1 are known (i.e., x, y, z are positions in Cartesian coordinates, $\dot{x}, \dot{y}, \dot{z}$ are velocities, θ, ϕ, ψ are Euler angles, and $\dot{\theta}, \dot{\phi}, \dot{\psi}$ are Euler angular rates). A total travel time (T_{tot}) for the table is assumed. The trajectory of each parameter (x) is calculated based on the four boundary conditions (x DP1, \dot{x} DP1, x DP2, \dot{x} DP2) and the travel time (t) varies from zero to T_{tot} . A polynomial of third degree is assumed for the table (and the POR) trajectory.

$$i.e., \quad Y = f(t) = C_1 t^3 + C_2 t^2 + C_3 t + C_4$$

where Y is the trajectory of $x, y, z, \theta, \phi, \psi$,
 C_1, C_2, C_3, C_4 are constants.

First, the table travel is checked to ensure that the table velocity and Euler angles will be less than the safe limit set for the simulator abort conditions. Second, the RMS end effector velocity, calculated from the table velocity, is checked to be less than the

maximum end effector velocity limit. In a dry run, the POR and the table trajectories will be checked for a successful real-time operation without triggering any singularity for the arm and other simulator abort conditions. During the dry run, the contact forces simulated by a second order spring model, the RMS health monitor functions, reach limit, control singularity etc., will be monitored. If the dry run is not successful, the total travel time may be increased to reduce the table velocity and the dry run is repeated.

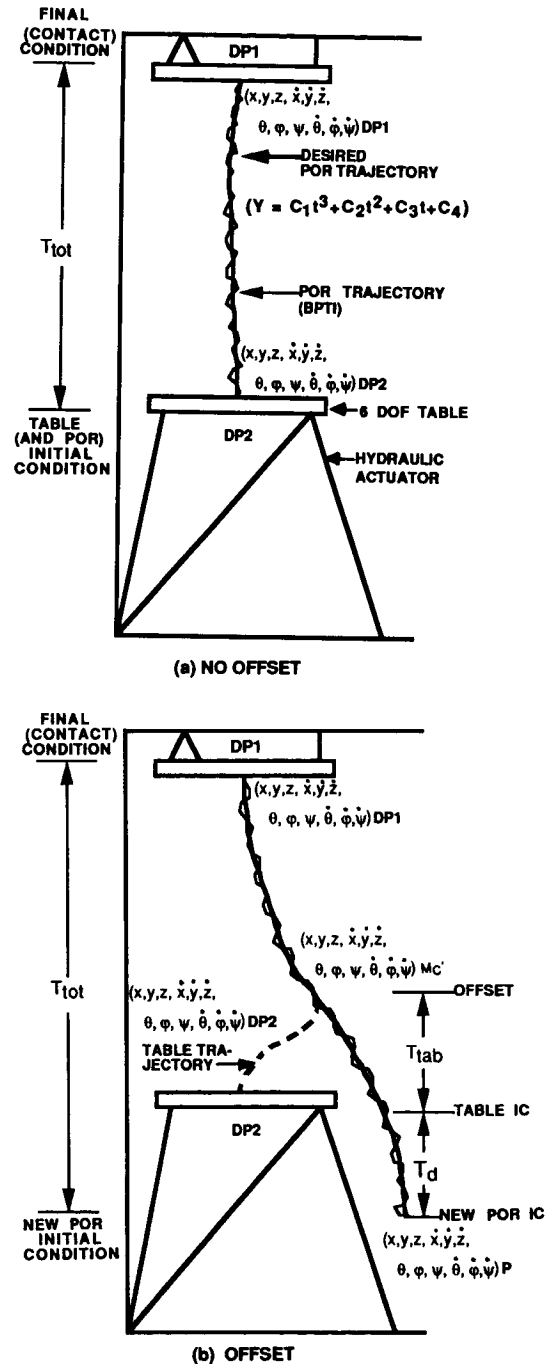
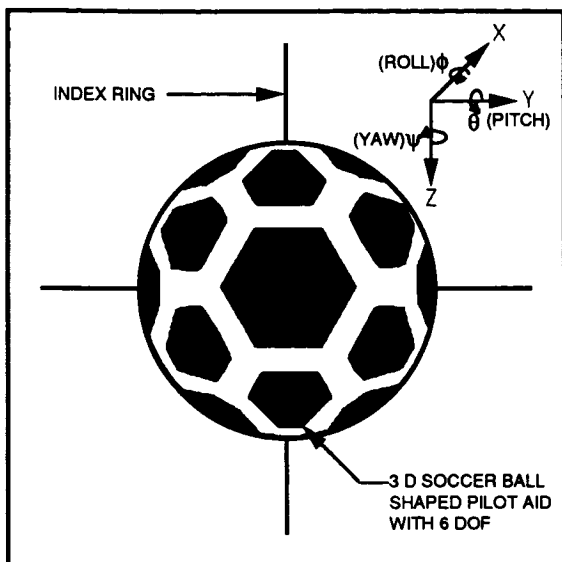
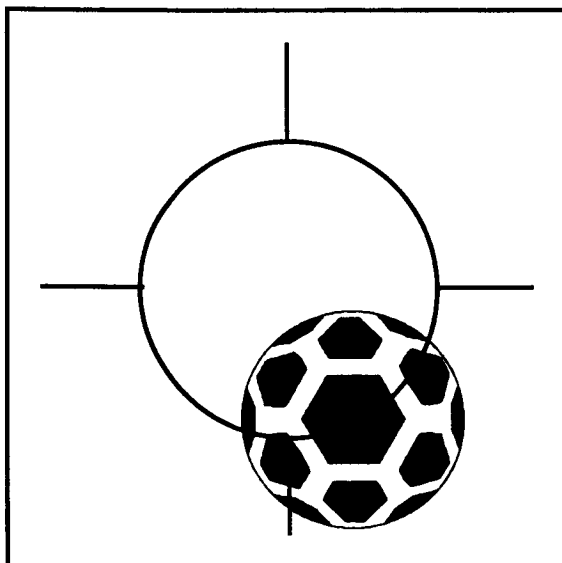


Figure 6. DYNAMIC INITIALIZATION



(a) PROPERLY MATCHED HAND CONTROLLER COMMANDS WITH BPTI COMMANDS.



(b) NEED TRANSLATIONAL (-X, -Y, -Z) HAND CONTROLLER COMMANDS TO MATCH BPTI COMMANDS.

FIGURE 8. PILOT AID DISPLAY

rates, health monitor information etc., and the POR translational and rotational commands. The RMS dynamics and geometry models calculate the POR position and attitude. Using the orbiter, the space station, and the table physical characteristics, the docking port relative geometry model calculates the docking port relative position, attitude and rates. The actuator command model calculates the required actuator stroke length. The results are applied to the hydraulic actuators through digital to analog converters. The table moves from the initial to the final condition where the initial impact occurs. When the docking mechanisms make a contact, the load cells measure the contact forces and the results are provided to the RMS dynamics model through the analog to digital converters and the load cell forces and moments model. Actual test data begins at the initial contact of the docking mechanisms and continues through the soft latch and a pilot or a RMS operator responds to the dynamic interactions to achieve the latching.

CONCLUSION

A real-time man-in-the-loop berthing simulator is being developed at NASA/JSC. A simulated orbiter robotic arm is used to conduct a berthing test. A dynamic initialization technic is developed to overcome the existing hardware and software constraints. The berthing test will examine the forces during contact conditions of the actual space station and the orbiter docking mechanisms. The test can be done automatically or manually to have a realistic robotic arm response at contact condition and to achieve latching. A 6 DOF pilot aid is developed for manual berthing operation. The berthing study can be extended for any two orbiting vehicles using a simulated robotic arm.

ACKNOWLEDGEMENTS

Acknowledgements are due to B.H. Strassner, Y.M. Kuo, D. Hayden, Y. Yang, A. Sylvester et al. The development of the berthing simulator is a joint effort of the Simulation Systems Branch, Systems Engineering Division, NASA/JSC, and the Simulation Development Department of Lockheed Engineering and Sciences Company.

REFERENCES

1. Strassner, Bernd, "Dynamic Docking Test System - Final Mathematical Model", NASA/JSC Internal Note 74-EG 23, July 1974.
2. Strassner, Bernd, "System Engineering Simulator On-Orbit Element Simulation Definition Document", LEMSCO - 2411, Lockheed Engineering and Management Services Company, April 1988.
3. Veerasamy, Sam, and Hayden, Don, "DDTS Berthing Simulation Critical Design Review", NASA/JSC, Lockheed Engineering and Sciences Company, January 25, 1990.